Collaborative virtual reality based advanced cardiac life support training simulator using virtual reality principles

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ABSTRACT

Background: Advanced Cardiac Life Support (ACLS) is a series of team-based, sequential and time constrained interventions, requiring effective communication and coordination of activities that are performed by the care provider team on a patient undergoing cardiac arrest or respiratory failure. The state-of-the-art ACLS training is conducted in a face-to-face environment under expert supervision and suffers from several drawbacks including conflicting care provider schedules and high cost of training equipment.

Objective: The major objective of the study is to describe, including the design, implementation, and evaluation of a novel approach of delivering ACLS training to care providers using the proposed virtual reality simulator that can overcome the challenges and drawbacks imposed by the traditional face-to-face training method.

Methods: We compare the efficacy and performance outcomes associated with traditional ACLS training with the proposed novel approach of using a virtual reality (VR) based ACLS training simulator. One hundred and forty-eight (148) ACLS certified clinicians, translating into 26 care provider teams, were enrolled for this study. Each team was randomly assigned to one of the three treatment groups: control (traditional ACLS training), persuasive (VR ACLS training with comprehensive feedback components), or minimally persuasive (VR ACLS training with limited feedback components). The teams were tested across two different ACLS procedures that vary in the degree of task complexity: ventricular fibrillation or tachycardia (VFib/VTach) and pulseless electric activity (PEA).

Results: The difference in performance between control and persuasive groups was not statistically significant ($P = .37$ for PEA and $P = .1$ for VFib/VTach). However, the difference in performance between control and minimally persuasive groups was significant ($P = .05$ for PEA and $P = .02$ for VFib/VTach). The pre-post comparison of performances of the groups showed that control ($P = .017$ for PEA, $P = .01$ for VFib/VTach) and persuasive ($P = .02$ for PEA, $P = .048$ for VFib/VTach) groups improved their performances significantly, whereas minimally persuasive group did not ($P = .45$ for PEA, $P = .46$ for VFib/VTach). Results also suggest that the benefit of persuasiveness is constrained by the potentially interruptive nature of these features.

Conclusions: Our results indicate that the VR-based ACLS training with proper feedback components can provide a learning experience similar to face-to-face training, and therefore could serve as a more easily accessed supplementary training tool to the traditional ACLS training. Our findings also suggest that the degree of persuasive features in VR environments have to be designed considering the interruptive nature of the feedback elements.

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1. Introduction

1.1. Background

Cardiopulmonary arrest (more commonly known as cardiac arrest) is the abrupt loss of pulmonary and cardiac functionality. Advanced Cardiac Life Support (ACLS) is a time-constrained medical intervention that requires coordinated action and effective communication of team members to resuscitate a patient facing imminent death from cardiac arrest [1]. According to American Heart Association (AHA) guidelines for ACLS, the first five minutes of the ACLS is the most critical time frame for corrective action to save the patient's life. During this short window a team must perform the interdependent tasks required for successful resuscitation [1]. ACLS requires the application of both cognitive skills (e.g., decision-making related to diagnosis of treatment scenario, identifying correct medications etc.) and psychomotor skills (, i.e. chest compressions) to perform effectively [2]. Theoretical aspects of ACLS guidelines may be learned in a classroom setting, but the attainment of procedural and communicative skills requires more hands-on practice, which traditionally has been acquired through face-to-face training under the supervision of a clinician certified as an ACLS instructor [3].

Although ACLS is a team based procedure, literature review has demonstrated the paucity of research on team training as more efforts have been focused on individual training [4,5]. Some of the reasons for such discrepancies are caused by difficulty in organizing training sessions according to each individual's schedule; difficulty in bringing the team members from disparate locations, and ease of conducting individual training in less time [6]. Since most of the patient care is delivered by clinician teams, it is imperative to train providers in team settings. In addition, training a team together has been observed to be a more effective way to improve the team performance [4]. Although frequent team based training helps in ACLS skill and knowledge retention [7], training on time-critical activities in a team setting is more complex and time consuming due to team coordination and communication requirements.

In a high fidelity ACLS training procedure, team members arrive at the practice room, which is typically equipped with a computer to control the training scenarios utilizing the higher fidelity manikin, a code-cart, IV-stand (intravenous), and wall ports for oxygen. The room has a layout that is typical of any patient room in the hospital. The ACLS team generally has 4–6 members [1], and the training procedure is initiated by assigning specific roles to these members. The performance of individual ACLS team members is monitored and evaluated by experts (instructors) throughout the training period.

The ACLS procedure requires the proper identification of cardiac arrest, which often requires identifying the patient's heart rhythm from an electrocardiogram (EKG). Pulseless rhythms can be broadly categorized into shockable (responds to electrical defibrillation) and non-shockable rhythms [8]. Patients with shockable rhythms such as ventricular fibrillation (VFib) and ventricular tachycardia (VTach) must be immediately defibrillated. However, asystole and pulseless electrical activity (PEA) are non-shockable rhythms, hence patients having one of these should not be defibrillated. VFib/VTach (12.8% occurrence) and PEA (41.6% occurrence) are the most common initial rhythms in hospitalized patients with cardiac arrest [9]. Additional interventions (i.e. administering medications) are provided according to the specific rhythm present.

1.1.1. State of the art ACLS training

Existing ACLS training predominantly involves face-to-face interactions among team members comprising of care providers. This is done through mock resuscitation codes. Hospitals use these to provide consistent protocol for regular ACLS training to their medical personnel. Such training is typically deployed using the concepts of clinical simulation performed on a patient substitute such as a manikin [7]. An instructor synchronously observes the team as they perform the required set of tasks for various scenarios, which are typically limited to five-minute sessions. The instructor performs a full evaluation of the team's performance during debriefing sessions conducted after the completion of the training session. Although high fidelity mock codes are the gold standard of ACLS training, there are a several issues that limit clinical professionals to learn or practice ACLS in short interval periods. For instance, the total cost associated with the overall setup for such a face-to-face training sessions is usually high due to prolonged setup times, training duration (3–4 h) and workers getting disrupted from their regular work schedules. The venues for such training sessions are also constrained by the availability of expensive training equipment.

Additionally, during conventional training, participants do not receive real time feedback despite getting observed synchronously. A majority of the feedback is provided during the post-training debriefing. Due to the limited availability of experts, scheduling the face-to-face ACLS training sessions is a challenge and thus is often provided to each clinician at a low frequency, usually once every 2 years when the ACLS class and certification are required.

1.1.2. Collaborative ACLS training using virtual reality

The recent advancements in computing power, storage and the availability of high speed network infrastructure has facilitated the use of virtual reality (VR) for performing collaborative tasks and team based training, especially in telemedicine domain. The development of Collaborative Virtual Environments (CVE) has provided users opportunities to perform various actions, while communicating and collaborating with others. CVEs have been used in various fields like gaming [10,11], online community building or socializing [12], advertising and e-commerce [13,14], educational and professional work [4,15–17]. CVEs are able to convey social dynamics like turn-taking, cooperation, appraisal, and communication to users. Additionally, users are given the flexibility to assume different roles like doctor, patient, trainer, trainee etc. Since ACLS is a team-based procedure with multiple roles, CVE is well-suited for designing an ACLS training simulator. ACLS team members can use a VR training simulator remotely, choose different roles, communicate with each other and perform tasks together. Such a training simulator provides various advantages over face-to-face ACLS training. Virtual ACLS training is a more cost-effective method for organizing ACLS training sessions, which could result in more frequent training. In addition, the ACLS trainees do not have to be present at the same physical location (distributed or non-collocated), which would save time currently required for travel to a common site for ACLS training. The simulator can provide real time feedback to the participants during training and can also generate performance reports, which allows trainers and/or evaluators to evaluate the performances without being present at the training sessions. CVEs are also capable of incorporating various persuasive components. Persuasive components are the interactive information technologies designed to change users' behavior or attitude [18,19]. Meaningful use of persuasive components such as real-time feedback, rewards, realism, and social presence enhances a learning environment [18]. Hence, unlike face-to-face training, VR based training can motivate users with novel means to reach the final goal during learning.

1.1.3. Objective of the study

We investigated the efficacy of using a virtual reality-based simulator intended for team training in ACLS. The design and implementation of the simulator was subjected to a comprehensive

evaluation through a comparative study of training outcomes in teams composed of nurses having prior ACLS certification. This work makes several major contributions. First, we designed and implemented a VR based training simulator having several unique features used for providing ACLS training in a team setting. These salient features include: (1) use of a haptic joystick for providing CPR training; (2) providing real-time feedback to users during the training; and (3) the ability to store training data into a remote database server for summative feedback and objective evaluation. Secondly, we report on the results of the comprehensive evaluation done to assess the efficacy of the VR-based ACLS training simulator. Finally, we also attempted to investigate the role of persuasive technologies used in the VR ACLS simulator. The findings of this study discuss the comparative performance of teams trained with a conventional ACLS method and those with the VR-based ACLS training simulator.

1.2. Related work

In this section, we briefly explain the extant research that guided the development of our work. There have been various studies that report the use of virtual worlds, especially those created in Second Life® (SL) [20]. SL is an online, 3D CVE or virtual world where users can create interactive virtual objects and navigate the world using a self-representation known as an "avatar". A dominant section of work on the applications of 3D virtual worlds focuses on behavioral treatments for mental health problems. For example, Gorini et al. [21] created an island, Eureka, in SL to use 3-D virtual worlds for online mental health applications and identified addiction as one possible area of intervention. Eureka was designed with two aims, the first to motivate and train users on how to improve their living habits and the second to be a tool for addiction prevention and treatment.

Another study conducted by Beard et al. [22] surveyed and categorized a range of health-related activities using SL for assessing the potential of virtual worlds for health information exchange and health behavior change. They classified virtual world applications into five categories: (a) Education and Awareness, (b) Support, (c) Training, (d) Marketing and Promotion of Health Services, and (e) Research. Applications of virtual worlds in categories (a) and (c) focused on cognitive aspects (such as adhering to a checklist), but lacked a means of providing group-based training on critical and time-sensitive medical procedure such as ACLS. They also typically did not have an objective evaluation and validation of the tool's effectiveness.

Wiecha et al. [17] described a teaching tool for continuing medical education in SL. That system was designed for physicians to refresh their skills on insulin therapy. Participating physicians had to listen to an instructional 40 min talk prior to interacting with two mock patients (automatic agents) using mouse click events. A questionnaire, consisting of ten questions that participants answered before and after the training, showed a significant improvement in the participants' scores after the training, which revealed that virtual worlds could be very helpful for continuing medical education. However, that system was created to provide individual training rather than team training. The paramedic training simulator designed in SL by Conradi et al. [23] was an interactive training simulation consisting of five different scenarios. The system was designed to determine the effectiveness of simulated problem-based learning. The system also provided an interactive platform where participants could collaborate with each other. Although the study showed that realism and suitable interaction engages students in learning, the study did not present the evaluation of the simulator other than feedback from the participants. Similarly, Boulos et al. [24] described the use of SL in developing cognitive skills related to neurological health education. The

authors also explained the potential of virtual worlds such as SL in medical and health education. Chodos et al. [3] created two different virtual cases in SL to provide training for emergency medical technicians and students across health disciplines. They discussed the importance of an SL based educational platform for communication skills training; however, the study did not describe the effect of the training on the users. Despite the numerous preliminary studies on the potential of CVEs in education and learning, the aforementioned studies did not integrate hands on skills training by integration of various sensors other than the mouse and keyboard; nor did they include procedures that require team members to collaborate to solve problematic medical cases like those in an ACLS procedure.

Our prior work on the development of a CPR training simulator [25] using a CVE called ActiveWorlds® [26] showed that the integration of a haptic joystick with a CVE was possible and able to provide CPR skills training. The results from that study showed participants were able to improve their hands on skills in maintaining a rate of 100 compressions per minute after the training. However, that system was only designed to provide individual training. The participants suggested that feedback on their performance during the training was both engaging and helpful during training. Various design principles for the implementation of persuasive technologies were adapted from Fogg's seminal book [18] and applied in Oinas-Kukkonen's article on persuasive systems design [19]. The study demonstrated an example of Nike + running system and how it integrates sequence of information presentation (tunneling), dialogue support (praise, rewards, alerts), and social support (cooperation, competition) to motivate users to change their attitude towards the system and make appropriate changes in their behavior. Burleson [27] also mentions the importance of providing alerts and/or instructions when a user is facing failure or the user is stuck at some point during problem solving.

The VR-based ACLS training simulator presented here builds upon earlier work where we developed a prototype for ACLS team training [28]. The training system integrated various persuasive components such as real-time feedback, timely instructions, scores, and temporal awareness. These were used to motivate the participants during training. The comparison of performance between teams provided with VR-based training (with and without persuasive components) and the teams provided with classroom-based training showed that the teams trained in VR, with and without persuasive components, performed slightly better than the teams with classroom training. Additionally, the teams provided with persuasive components during VR training performed better than the ones without it. However, the participants did express feeling a significant lack of system responsiveness during VR training caused by a delay in internet connectivity. Another limitation of the study was that none of the participants had ACLS skills or knowledge prior to the training.

2. ACLS virtual reality simulator: conceptual foundations and architecture

In this section, we first describe the conceptual foundations used for developing the VR-based training simulator and then explain the design and implementation of the virtual reality simulator in detail while describing various features of the ACLS VR simulator.

2.1. Virtual reality principles

2.1.1. Immersive technologies
Virtual reality can be defined as a computer-generated, fully or partially interactive three-dimensional environment. In order for a

VR environment to be suitable for training, Oblinger et al. [29] suggested five key feature types be considered in development: Social, research, problem solving, transfer, and experiential. **Social** features foster a sense of community or competition during training; **Research** features motivate the participants to explore and learn about the virtual environment; **Problem solving** features require application of existing or learned skills to perform tasks in order to reach a desired goal; **Transfer** features ensure that skills attained in the virtual environment are useful in solving real world problem(s); **experiential** features allow for multimodal user interaction with the **environments** in ways that emulate real world observations. Some of the applications of these features are presented in [17,30–34].

The aforementioned features were critical for the design, development, and evaluation of the VR-based ACLS simulator. The immersive environment allowed the users to actively engage in the simulated training [35] by enabling them to form ACLS teams, to explore and learn about the virtual environment, and to perform collaborative tasks together. The simulator also integrated multiple modalities (i.e. visual, auditory, and haptic).

2.1.2. Persuasive technologies

Immersion is an important design aspect of the proposed ACLS VR-based training simulator. Users need to be motivated and/or guided in performing the required tasks. In order to change users' behavior or attitude Fogg [18] suggests integrating seven key techniques for accomplishing persuasiveness (i.e. reduction, tunneling, tailoring, suggestion, self-monitoring, surveillance, and conditioning). Several of these features when integrated within VR training may change user behavior and/or attitude toward learning skills. Most persuasive techniques that have been used in VR-based simulators have been limited to individual training purposes. By extension VR-environments designed for teams should benefit by integrating persuasive technologies at two different levels: individuals within a team and the team as a whole. We designed the ACLS VR-simulator using three technologies – tunneling, tailoring, self-monitoring and surveillance.

Tunneling guides the user through the entire procedure until the goal is obtained. **Tailoring** insulates the user from excessive information in a given context by minimizing presentation according to need. **Self-monitoring** and **surveillance** allow users to monitor their own and others' performance respectively. Several fitness apps or training tools [36,37] have incorporated all or a part of these technologies to encourage individuals of healthy living; however, they did not attempt to quantify the contribution of these techniques on user experience.

In the VR ACLS simulator, each user has a set of tasks specific to the team role assumed. We implement tunneling by providing messages to separately guide each user (e.g. "Check pulse", "Get medication ready"). The VR-based ACLS simulator uses tailoring technology by limiting displayed messages relevant to each role. For example, "Get medication ready" is shown only to the medicator, whereas, "Shock the patient" is shown only to the defibrillator. In order to incorporate self-monitoring and surveillance, two different levels of feedback message were provided: local messages shown to the users who performed the tasks and global messages shown to all users. The local messages help users to monitor themselves whether they are performing the required tasks properly; whereas the global messages help users to monitor task performed by other users.

2.2. System design and architecture

Fig. 1 shows the system architecture of the VR-based ACLS training simulator (adapted from [38]). The architecture is based on four different layers: roles, user interfaces, real-time feedback components, and ACLS servers. Each layer comprises of individual components that interact with each other. The six different roles within the ACLS 'roles' layer interact among themselves and also with the system using various user interface modules from User Interfaces (UI) layer. The UI layer provides timely alerts and feedback, which are originated from the Real-time Feedback layer, to the users in the roles layer. The ACLS server layer consists of various servers that form the building blocks of the simulator. The *Unreal Development Kit* (UDK) [39] server in this layer integrates the ACLS algorithm module that triggers the real time feedback.

There are four key modules used in the simulator: user interface module, algorithm module, database module, and feedback module.

2.2.1. User interface module

In addition to various basic interface components such as mouse and keyboard, the design interface has three major components-visual, voice, and haptic (i.e. touch-based). The visual interface allows the user to interact with the training system, to follow the instructions provided on the screen, and to perform the required tasks using a mouse or a keyboard. It is also used to display feedback to the users. The visual user interface (Fig. 2) has been designed using the UDK gaming engine. It includes several design artifacts such as a virtual ACLS training room, tools and equipment that are required during an ACLS session, and the avatars that represent different characters controlled by the real individuals playing specific roles in ACLS. During the VR training, the default setting is that each user can only see a view for his/her ACLS role. However, there is a feature that allows them to see other members in the virtual training room by activating a key. The auditory interface allows the users to communicate with each other during the ACLS training session. This interface has been developed using *TeamSpeak*® [41], which is then integrated into the UDK environment. The haptic CPR interface is designed to provide psychomotor skills training to the users. We used the *Novint Falcon*® [42] haptic device and integrated it with the training system so that the number and depth of the compressions during the CPR procedure could be recorded. The haptic device provides force feedback only to the user who is performing the CPR. As a result of this feedback, the user's avatar performs the CPR actions in the virtual environment, which is visible to other members participating in the session.

2.2.2. Algorithm module

The algorithm module consists of rules that are based on the traditional approach of evaluating the performance of a team in a face-to-face environment using human evaluators. These evaluators assess the task performance and record task completion time. These rules are fired when a task processing is underway or completed. (Please refer to Table 1 for a complete list of tasks and timing rules). Based on these rules, each correctly performed task in a training session is assigned a score, which is stored into the database and also displayed to the users in the form of the patient-health outcome using the feedback module.

2.2.3. Database module

The database module is based on *MySQL*® database management system [40] and stores all the data generated related to the training sessions such as the user performance details. The system has been designed to strictly maintain the confidentiality of the participants so that their co-workers and/or employers cannot access their performance results. Personal identifiers (i.e. name, date of birth, address, and other identity numbers) are not stored in the database. Instead, each user is assigned a unique randomly generated ID at the time of enrollment.
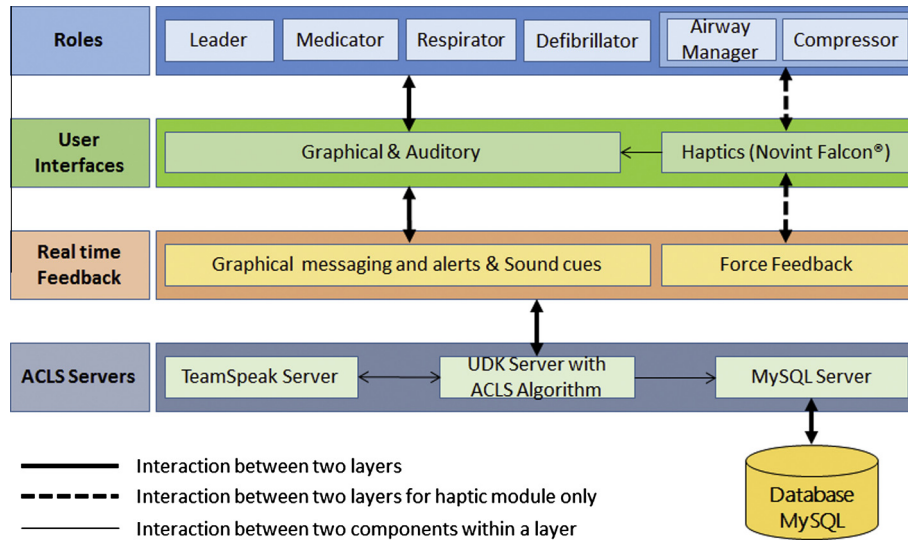
Fig. 1. System architecture.

Fig. 2. Role-based user interfaces (top left to right: leader, respirator, defibrillator; bottom left to right: compressor, medicator, airway manager).

2.2.4. Feedback module

The feedback module involves the task of providing visual (including textual) and auditory feedback to the users during and after a training session, based on their performance during the training session. The feedback includes various text-based instructions and alerts to assist participants in completing their task on time and communication bar that identifies who is speaking during the virtual training session. Real-time feedbacks/messages are integrated with the visual interface in order to guide the users during training, in addition to informing them about task completion. Although the users are communicating with each other, they might

forget to perform some tasks during training. These feedback messages are independent to each role and are used to remind users about performing the tasks correctly. Once the information is obtained through the *algorithm* module, real-time feedback is immediately dispatched to the visual interface. This module retrieves the information from the *database* module, and displays the feedback summary to the user through the visual as well as auditory interfaces.

Fig. 1 also shows the information flow from one module to another in the system. The haptic feedback is used by a locally stationed user who is performing the CPR on the haptic device. When

Table 1
Tasks used in scoring metric for quantitative evaluation.

Task Id	Task	AHA Guideline	Time threshold (in seconds)
T1	Time of pulseless recognition	As soon as possible	$T1 \leqslant 20$
T2	Time CPR/BLS initiated	Within 10 s of pulseless recognition	$T2-T1 \leqslant 10$
T3	Initial rhythm recognized	Within 60 s of code cart arrival	$T3 \leqslant 60$
T4	Time of initial defibrillation	Within 15 s of rhythm recognition	$T4-T3 \leqslant 15$
T5	Time of 1st drug	Within 3 min	$T5 \leqslant 180$
T6	Time of 2nd defibrillation	Within 2 min of first defib	$105 \leqslant T6-T4 \leqslant 135$
T7	Time of 2nd drug	Within 2 min of first drug	$T7-T5 \leqslant 120$
T8	Time of 3rd defibrillation	Within 2 min of second defib	$105 \leqslant T8-T6 \leqslant 135$
T9	Time of 3rd drug	Within 2 min of second drug	$T9-T7 \leqslant 120$ s

a participant starts performing CPR, it triggers the CPR animation sequence in the CVE, which is visible to all the participants who are playing other roles during the ACLS training. In addition to activating the animation sequences, the system also provides visual cues and instructions on what actions are next for the participant(s), such as delivering medications to the patients and putting oxygen bags.

3. Experimental design and setup

3.1. Experimental design

The experiment was conducted at Banner Health Simulation Education and Training (SimET) Center, Phoenix, Arizona and was approved by the internal review boards (IRB) of Banner Health and Arizona State University. We enrolled one hundred fifty-six ACLS certified participants from Banner Health, Arizona resulting in twenty-six teams. Each participant was randomly assigned to one of the six ACLS roles: compressor, medicator, defibrillator, airway manager, respirator, and leader. Each role was associated with performing a specific set of tasks. Though the AHA guidelines do not specify names for each role, we assigned the roles oriented names to the avatars designed in the ACLS CVE. The compressor, respirator and airway manager are responsible for performing high quality cardiopulmonary resuscitation (CPR). The compressor performed compressions, the airway manager kept the patient's airway open and the respirator used the ambu-bag to provide ventilation. The medicator's prime role was to administer the required medications. The defibrillator attached the EKG leads to the patient's chest to identify the arrhythmia and defibrillated the patient's heart if necessary. The leader monitored the team interventions and guides the team through synchronous execution of the ACLS guidelines.

Each team was randomly assigned into one of the three treatment groups: control, persuasive, or minimally persuasive. The teams in the control group were provided with traditional manikin-based training, whereas the ones in other two groups were provided with training on our virtual reality based simulator. The teams in the persuasive group were provided with visual aids such as communication bar, instructions, task completion messages, and alerts that are available for all team-members as well as the ones that are specific to each role during the VR-based training, whereas the teams in the minimally persuasive group were provided with only text-based task completion messages for each role. Alerts and instructions were not provided to the teams in the minimally persuasive group.

Each team was ideally set to have 6 members playing different roles. Variations in the team sizes occurred due to unanticipated cancellations and no-shows from participants. This resulted in three teams with five members and two teams with less than five members. This is similar to situations that are often encountered in real life hospital scenarios. In-hospital resuscitations efforts by teams having fewer than six clinicians occur frequently. For the proper functioning of the virtual reality platform, teams with less than five members were not included in the study. In case of teams with five members, medicator and defibrillator roles were assigned to one person from a team. Thus, eight teams were distributed across the three treatment groups. The different phases of the experiment are shown in Fig. 3. We now describe the different phases of the experiment.

3.1.1. Initial survey

In this phase, the participants signed the consent form and filled out an initial survey, which was designed to capture participants' demographic information, prior experience with in-hospital
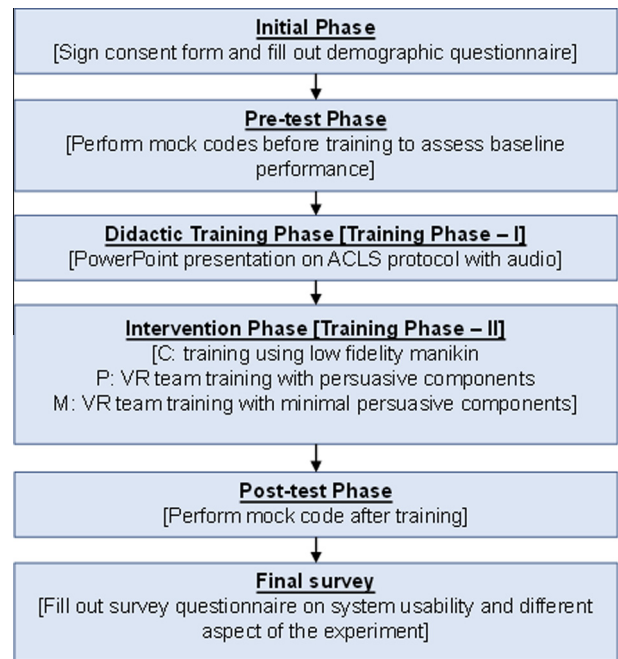
Fig. 3. Different phases of the study: (C: control; P: persuasive; M: minimally persuasive groups).

resuscitation, years of training in CPR and ACLS, self-assessed proficiency in each and prior exposure to computer games. The demographic information was collected for future study on the retention of learned skills.

3.1.2. Pre-test phase

Each team's ACLS skills were tested prior to providing any kind of training, which served as the baseline measure. The teams were tested for two ACLS scenarios: V-Fib and PEA, on a high-fidelity manikin in order to assess their baseline performance as evaluated by two expert ACLS trainers. These served as the two variations of tasks that the ACLS teams performed. The evaluators were blinded to the group formation. The order of the scenarios was randomly chosen. Each mock-code lasted for approximately five minutes or whenever the team had completed the appropriate resolution point for the scenarios (third shock in case of VFib; and the administered drug is Narcan for toxicity in case of PEA). For each team, the evaluators recorded the time for each task in an electronic checklist.

3.1.3. Didactic training phase

Teams from all three treatment groups were provided with a 25 min didactic lecture designed by expert ACLS trainers and delivered through an automated presentation with pre-recorded voice support. This lecture was the first part of the training during this experiment and was common to all teams. It provided the participants a refresher on the key points of the ACLS guidelines that each participant was originally exposed to and tested on during their previous certification. The content covered included responsibilities for each role, current guidelines for basic life support (BLS) and ACLS, including arrhythmia dependent differences in the ACLS algorithm, delivery of medications, the essentials of team work and communication.

3.1.4. Intervention phase

In this phase, the treatment groups were provided with hands-on training. The training intervention varied across different treatment groups. In this phase, teams in the control group were

provided with traditional face-to-face training using a low fidelity manikin facilitated by a trainer in the same room. The participants from the control group practiced airway, respirator, compressor and defibrillator roles for at least 2 min per role.

The airway role focused on opening the airway and inserting oral airway; the respirator role included training on giving two breaths (ventilation) over one second each; for the compressor role, the major objective was to manage proper compression rate of 100 per minute maintaining 30:2 compression to ventilation ratio, proper depth and recoil; and the defibrillator role focused on applying patches on the manikin, using an automated external defibrillator (AED or defibrillator in common) device, analyzing the rhythm and delivering shock appropriately.

The other two groups received training in a virtual reality environment for which they had no prior exposure. Therefore, each team underwent a twenty minute guided single-user tutorial to familiarize with the new user interface. Members also watched a video that introduced them to their specific roles. Two separate rooms were allocated to spread the team members across different locations as would be the case when training remotely through a VR platform. Four of the participant roles – medicator, defibrillator, respirator, and compressor – were located in one of the rooms while the remaining two roles – airway manager and leader were located in a separate room. This was done to provide a sense of perceived virtual environment to the participants while undergoing ACLS training through CVE. None of the users were able to see the screens of other users. However, they were able to communicate with each other using headsets and the audio application integrated into the simulator.

The persuasive group was provided with real-time feedback components as mentioned in the System Design section. The treatment group designated as minimally persuasive used CVE integrated with certain assistive features, such as a help menu, that were also included for the persuasive treatment group. Participants in both persuasive and minimally persuasive groups were trained individually on how to perform various ACLS related tasks (corresponding to their respective groups) in the virtual reality simulator. Each participant was trained individually for twenty minutes. Technical support was provided to all VR participants whenever there was any unforeseen difficulty using the simulator.

The teams in the persuasive and the minimally persuasive groups were provided with team ACLS training through a five-minute virtual reality mock code. The participants were required to login from different systems simultaneously and perform the tasks in a coordinated manner to save a virtual patient. No technical support was provided during this phase. This session typically lasted for thirty minutes. Each team was provided with randomly selected scenarios with different patient histories and one of two arrhythmias, V-fib or PEA. Modeling a comprehensive scenario representing all the large number of factors that could cause PEA is difficult, hence we modeled the PEA task based on only one contributing factor, toxins. However, the teams were unaware of this.

3.1.5. Post-test phase

A post-test trial that was similar to the pre-test in the design was performed immediately after the completion of the *intervention phase*. In this phase, all the teams were tested on the high fidelity manikins in front of human evaluators. They were provided with randomly selected ACLS scenarios (either PEA or VFib/VTach). The patient information for the scenarios in the post-test was changed from the pre-test. Two evaluators were present to evaluate the performances of the teams during the test sessions.

3.1.6. Final survey

In the final survey, the participants were asked to answer a questionnaire regarding the training experience. The questionnaire

was a means of objective data collection that would be used in future studies. The experiment session ended after the participants submitted their answers to the final survey questions.

The test sessions (pre and post) were also video recorded, which enabled us to verify the times noted by the evaluators by manually calculating each team's time from the recorded video sessions. We were also able to fill in time values for teams that were missing in the evaluators' checklist.

3.2. Scoring metric

ACLS experts were used as evaluators for the participants and used an assessment tool to evaluate the teams. The assessment tool, an electronic checklist, was developed and validated internally by a team of expert ACLS trainers within Banner Health. It was built in MS Excel® and included items deemed critical for the assessment of team performance by human observers. These items were primarily tasks that correspond to AHA guidelines for ACLS. Due to the intense cognitive load placed upon evaluators observing teams with multiple members performing task in series and parallel, efforts were made to minimize the complexity of this tool's interface. Therefore, simple checklist having mouse-activated buttons that could easily record time stamps was used. This checklist was then provided to the researchers, who utilized the instrument to store observed actions. Efforts were made to increase the objectivity of assessments. To this end, video recording of the training session was also used to tally evaluator's recorded observations with the events recorded on video. In case of any inconsistencies, it was reported to the evaluators and appropriate measures were taken to understand and resolve the conflict. A scoring metric was then created based on the teams' adherence to the ACLS guidelines created by AHA. According to these guidelines, each task must be completed within a specified time frame. Since the guidelines do not provide exact times required for performing various ACLS tasks, we used the expert opinions of ACLS trainers to determine the acceptable times required to complete each task in the ACLS test. The scoring metric and the tasks used are listed in Table 1. The top level tasks such as medication and defibrillation were complex tasks composed of sub-tasks such as identifying correct levels of energy while delivering shock for defibrillation, choosing correct medications, and ordering the correct dosage for the medication. In order to get a full score on the main level task, a team needed to perform all the sub-tasks for the main task correctly.

After developing the scoring metric, the next step was to assign appropriate weights to each task for different scenarios so that correctly completing a task of higher importance would award a team higher point compared to correctly performing a lower weight task. The metric consisted of nine different tasks for VFib/VTach cases and six different tasks for PEA cases. The study utilized ten ACLS expert trainers to rate the tasks on a nominal scale of 1–5, 1 being the least priority tasks and 5 being the highest priority tasks. The ACLS experts provided the ratings based on the AHA guidelines on the ACLS procedure. The various tasks (first column) and their evaluator ratings are shown in Table 2. The first row represents the 10 different raters (E1 to E10).

The weights provided by the experts for all tasks were found to have very similar scores with range varying from 0.100 to 0.128 and mean of 0.111 ± 0.009. Therefore, we assigned equal weights to all the tasks performed during the ACLS training sequence. In Table 2, there are six tasks for PEA and nine tasks for VFib/VTach selected for performance evaluation (marked by "p" and "v") in terms of percentage score. Since all tasks have equal weights, each correctly performed task in a PEA scenario has a score of 16.6 points (total score, 100, divided by the number of tasks in PEA, 6); and each correctly performed task in a VFib/VTach scenario

equals a total score of 11 points (total score, 100, divided by the number of tasks in VFib/VTach, 9,).

The quantitative measures of cardiopulmonary resuscitation (CPR) skills such as rate, depth, and recoil of CPR are beyond the scope of this study. The primary focus of this paper is on assessing the impact of a VR-based collaborative training simulator on procedural training aspects of ACLS.

4. Results

We used IBM SPSS Statistics version 19 [43] to analyze the data. The teams were first tested in a mock-code training scenario using high fidelity manikins in order to obtain their baseline performance before the training. The treatments groups were randomly distributed across two ACLS task scenarios – PEA and VFib/VTach.

4.1. Initial survey

Total of one hundred and forty-eight (148) participants were enrolled into the study, out of which, only ten (10) were male. The average experience of the participants on ACLS in terms of years was 7.4 (range: 0–38). The distribution of the experience across the groups were: 7.84 (range: 1–30) years for control group; 7.04 (range: 1–20) years for minimally persuasive group; and 7.13 (range: 0.5–38) years for persuasive group. Similarly, the average height of the participants was 65.48 inches (range: 59–76) (control: 66.4 (range: 61–76) inches; minimally persuasive: 65.2 (range: 60–72) inches; persuasive: 64.8 (range: 59–74) inches), and the average weight of the participants was 159.4 lbs. (control: 154.8 (range: 116–220) lbs. ; minimally persuasive: 166 (range: 105–300) lbs.; persuasive: 153.9 (range: 104–280) lbs.).

4.2. Pre-test

One of the major objectives of this study is to assess the performance of the ACLS CVE for training purposes. Adherence to the guidelines provided by the AHA when performing various tasks in the entire ACLS procedure is an important criterion in determining the level of team performance. The performance of the teams during the pre-test indicated that the teams were highly non-compliant with AHA guidelines for the ACLS procedure. After the pre-test, we found that only 39.4% of total 360 tasks (control – 39.1%, 47 out of 120 tasks; persuasive – 35.8%, 43 out of 120 tasks; minimally persuasive – 43.3%, 52 out of 120 tasks) were performed correctly.

We performed Shapiro–Wilk test to assess normality for our data. The results showed that the data violated the normality assumption ($P = 0.03$). Mann–Whitney U test, which does not require data to be normally distributed, was performed to understand the difference in pre-test performance between two groups at a time. We compared the pre-test performance of the three treatment groups which did not show any statistically significant difference (control vs. persuasive: $P = .78$ for PEA and $P = .55$ for VFib/VTach; control vs. minimally persuasive: $P = .55$ for PEA and $P = .51$ for VFib/VTach; persuasive vs. minimally persuasive: $P = .38$ for PEA and $P = .36$ for VFib/VTach).

4.3. Post-test

After the pre-test was performed, didactic training as well as hands-on skills training (explained in "Intervention Phase") were provided to the participants, followed by the post-test. Their performance was evaluated after the post-test. We performed the Mann–Whitney U Test to understand the difference between the performances of the control and persuasive groups. We did not find the differences in the performance to be statistically significant ($P = .37$ for PEA; $P = .1$ for VFib/VTach). Similarly, the difference in the performances between the persuasive and minimally persuasive groups ($P = .1$ for PEA; $P = .63$ for VFib/VTach) was also found to be statistically insignificant. However, the difference in the performances between the control and minimally persuasive groups was found to be statistically significant ($P = .05$ for PEA; $P = .02$ for VFib/VTach). This shows that the performance of the persuasive group and the control group were at-par whereas the performance of the minimally persuasive group was par below that of the control group. Pre-test data collected prior to providing any form of training during the experiment suggests that ACLS skills not only degrade over time but also reflect the importance of a thirty minute training session. After under-going the thirty minute training session, we also noticed that the adherence to the AHA guidelines increased on an average to 58.3%, n = 360 (control – 68.3%, 82 out of 120 tasks; persuasive – 57.5%, 69 out of 120 tasks; minimally persuasive – 49.1%, 59 out of 120 tasks).

Finally, we used the Wilcoxon signed rank test to compare the pre-post performance of teams within each treatment group. All three groups were found to have improved their average performance during the post-test sessions in comparison to the pre-test sessions. The performance of the control group improved significantly during the post-test sessions compared to the pre-test sessions ($P = .02$ for PEA; $P = .01$ for VFib/VTach). The performance improvement of the persuasive group was also statistically significant ($P = .02$ for PEA, $P = .048$ for VFib/VTach). However, the
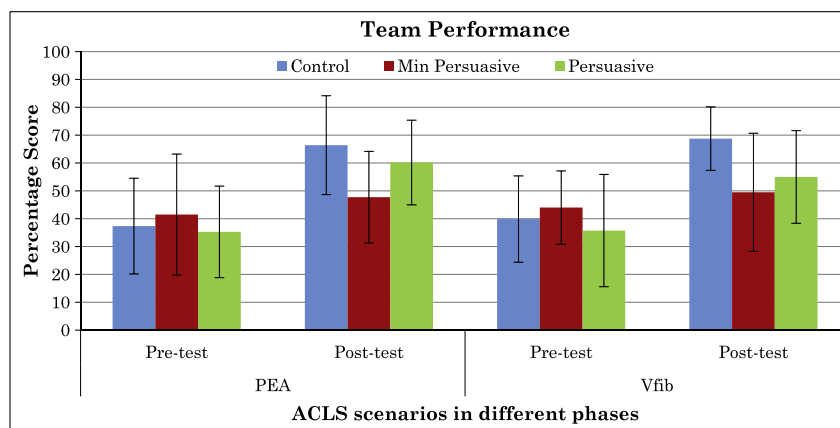

Fig. 4. Overall performances of three different treatment groups in the study.

Table 2
Tasks list and priorities according to 10 ACLS experts (1 – lowest, 5 – highest) (p – PEA, v – VFib/VTach).

Description	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Avg	Weight
Time of pulseless recognition (p,v)	5	5	4	3	3	4	5	5	5	2	4.1	0.114
Time of CPR/BLS initiation (p,v)	5	4	4	5	3	5	5	5	4	4	4.4	0.123
Time of initial rhythm recognition (p,v)	5	4	4	4	3	4	5	4	4	4	4.1	0.114
Time of initial defibrillation (v)	5	4	4	4	4	5	5	5	5	5	4.6	0.128
Time of first drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.106
Time of second defibrillation (v)	4	3	4	4	4	3	4	3	4	5	3.8	0.106
Time of second drug (p,v)	4	3	4	5	4	4	4	3	3	4	3.8	0.106
Time of third defibrillation (v)	4	3	4	4	4	2	4	3	4	5	3.7	0.103
Time of third drug (p,v)	4	3	3	5	4	3	4	3	3	4	3.6	0.1
Total											36.4	

Table 3
Comparison of performance between (b) and within (w) groups.

Comparison groups	Test (Pre/Post)	Statistical significance in difference (PEA)	Statistical significance in difference (VFib/VTach)
C vs. P (b)	Pre	No difference ($P = .78$)	No difference ($P = .55$)
C vs. M (b)	Pre	No difference ($P = .55$)	No difference ($P = .51$)
P vs. M (b)	Pre	No difference ($P = .38$)	No difference ($P = .36$)
C vs. P (b)	Post	No difference ($P = .37$)	No difference ($P = .1$)
C vs. M (b)	Post	Significant difference ($P = .05$)	Significant difference ($P = .02$)
P vs. M (b)	Post	No difference ($P = .1$)	No difference ($P = .63$)
C (pre vs. post) (w)		Significant difference ($P = .02$)	Significant difference ($P = .1$)
P (pre vs. post) (w)		Significant difference ($P = .02$)	Significant difference ($P = .05$)
M (pre vs. post) (w)		No difference ($P = .45$)	No difference ($P = .45$)

performance improvement of the minimally persuasive group was not statistically significant for both scenarios ($P = .45$ for PEA, $P = .46$ for VFib/VTach). The summary of the results from pre and post test phases are shown in Fig. 4 and Table 3.

5. Discussion

5.1. Principal result

This paper presents a novel approach for conducting collaborative ACLS training using virtual reality principles that offer the capability to conduct a comprehensive and objective evaluation of the care team. The study results also present an important case for integrating the elements of persuasive technology in VR training sessions. Such elements can provide timely feedback to the trainee, which may have implications for quicker error detection and correction to the proper technique being learned. Our findings suggest that while the performance of teams in the traditional face-to-face training was marginally better than the teams in the persuasive group, there was no statistically significant difference in the improvement of skills between the groups. Past research studies have shown that the conventional method of conducting ACLS training is expensive and difficult to organize. Additionally, all the ACLS trainees and evaluators are required to be present at the same location, limiting accessibility and frequency of training. On the contrary, the VR-based ACLS training simulator is significantly cheaper, easier to organize, and facilitates users to practice in a team from disparate locations without requiring an evaluator. An evaluator could generate the training report offline and provide feedback on the performance from a remote location.

5.2. Limitations and future possibilities

There was limited difference in the performance of the minimally persuasive group when compared to the other two groups. When comparing the performance of persuasive and minimally persuasive groups during VR-based training, on average the persuasive group performed better than the teams in the minimally

persuasive group. Fig. 5 shows the performance of the two groups during those VR-based training sessions. This may be attributed to the effectiveness of persuasive elements in the VR-based ACLS simulator. Various features in persuasive groups help improve the performance due to timely intervention and correction. We limited the training duration to thirty minutes for the VR group, which may not have been sufficient to become accustomed to the virtual environment while simultaneously learning the ACLS skills. Future studies could be designed to include a longer introduction to the system.

A limitation of this study was that there were only eight teams in each treatment group. The study required extensive evaluation of the VR-based simulator by enrolling ACLS certified nurses. Because of their conflicting or busy schedules, we had a limited number of ACLS participants (156) for this experiment. Out of these, eight participants were absent on the day of the study. Lacking available substitutes for immediate replacement of the absentee participants resulted in the reduction in our sample size to 148. Future studies must be conducted over a larger sample size for accomplishing greater validation of the results.
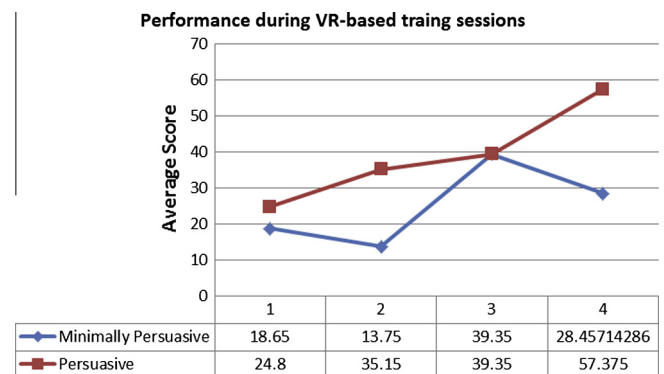

Fig. 5. Performance of persuasive and minimally persuasive groups during VR-based training sessions.

Finally, this study did not focus on the quantitative analysis of ACLS measures and the qualitative analysis of communication among the team members. The quantitative measures include variables such as compression rate, depth, and recoil. Unlike conventional ACLS training, VR-based training simulators must be able to record such quantitative measures, track the performance over prolonged periods of time, provide summative feedback to the users, and automatically evaluate the performance of teams as well as individuals. Shetty et al. [44] reported that leadership flexibility and situational changes that were required in case of deviation from ACLS protocol were more important factors rather than the following the protocol itself. The analysis of the communication between the team members during ACLS mock codes is a future work.

Despite the limitations, our study showed that VR-based ACLS training can be an effective supplement to the conventional method of training. It demonstrates how various training systems that integrate multisensory devices into a virtual, collaborative environment for time critical procedures could be designed and effectively utilized. We foresee a vast array of systems that can be developed based on similar design concepts and architecture. An example of this is the patient monitoring system in which patients can be monitored remotely using wearable sensors in a VR-based environment while preserving the privacy of the user. There are other team-based activities such as Advanced Trauma Life Support (ATLS) and Pediatric Advanced Life Support (PALS) for which similar training simulators could also be developed.

5.3. Conclusion

The VR-based ACLS training tool introduced and tested in this study can complement the state-of-the-art ACLS training methods used in hospitals so that more frequent and accessible training sessions can be conducted with trainees in disparate locations. The VR-based ACLS training simulator, coupled with persuasive components, is a novel platform with potential to be easily integrated with conventional approaches of providing ACLS training curriculum. In addition to providing economic advantage, the VR-based ACLS training also provides the capability to more objectively evaluate the learned skills of participants. Each participant is able to monitor their scores during and after the tests, enabling them to track short and long-term trends in their ACLS skills, which would be very difficult to provide in the traditional training formats.

Acknowledgments

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